AERIAL OBSERVATION OF OIL

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Introduction

Aerial reconnaissance is an important element of effective response to marine oil spills. It is used for assessing the location and extent of oil contamination and verifying predictions of the movement and fate of oil slicks at sea. Aerial surveillance provides information facilitating deployment and control of operations at sea, the timely protection of sites along threatened coastlines and the preparation of resources for shoreline clean-up. The aim of this Technical Information Paper is to present advice and guidance on conducting aerial reconnaissance at sea effectively.

Figure 1: Use of aircraft allows a rapid understanding of the spread of floating oil and the effectiveness of any response

Strategy for aerial reconnaissance

At the outset of an incident, reports from reconnaissance flights are often vital to establish the nature and scale of the pollution problem. Subsequent flights should be made regularly, commonly at the beginning or end of each day, so that the results can be used to plan response operations (Figure 1). The flights, including their time-tabling and flight paths, should be coordinated to avoid unnecessary duplication. As the pollution situation is brought under control the need for flights will reduce and disappear.

Safety considerations are paramount and the aircraft pilot should be consulted on all aspects of the reconnaissance operation prior to departure. Those taking part in a flight should be regularly and thoroughly briefed beforehand on the safety features of the aircraft and procedures to be followed in the event of an emergency. Suitable personal protective equipment, such as life jackets, should be available and used.

When selecting the most appropriate aircraft, consideration needs to be given to the location of the spill, the nearest airstrip and refuelling stations, and the likely extent of sea and coastline to be included in a reconnaissance flight. Any aircraft used for aerial observation must feature good all-round visibility and carry suitable navigational aids. For example, if there is a choice of aircraft design, better visibility is afforded by high-mounted wings. Over near-shore waters the flexibility of helicopters is an advantage, for instance in surveying an intricate coastline with cliffs, coves and islands. However, over the open sea, there is less need for rapid changes in flying speed, direction and altitude, and the speed and range of fixed-wing aircraft are more advantageous. Aircraft selection should take into account the operating speed, for if this is too fast the ability to observe and record oil will be reduced, and if it is too slow the flying distance will be limited. For surveys over the open sea, the extra margin of safety afforded by a twin or multi-engined aircraft is essential – and may in any case be required by government regulations.

The type and size of an aircraft will limit the number of people able to take part in a flight. For small aircraft, and helicopters in particular, the number of passengers can substantially affect fuel consumption and thus the endurance of the aircraft. If there are two or more observers on a surveillance flight, they should work closely together to compare and confirm sightings. The lead observer directing the pilot should be experienced in aerial surveillance and be able to reliably detect, recognise and record oil pollution at sea. There should be a consistency of at least one observer throughout a series of flights, so that variations in reports reflect changes in the state of oil pollution and not differences between the perceptions of the observers.

Preparations for aerial reconnaissance

A flight plan should be prepared in advance, taking account of any available information that may reduce the search area as much as possible. It should also take account of any flight restrictions, some of which may be specifically imposed as a result of the spill. For example, it may be prohibited to fly over the shipping casualty, foreign or military airspace or certain

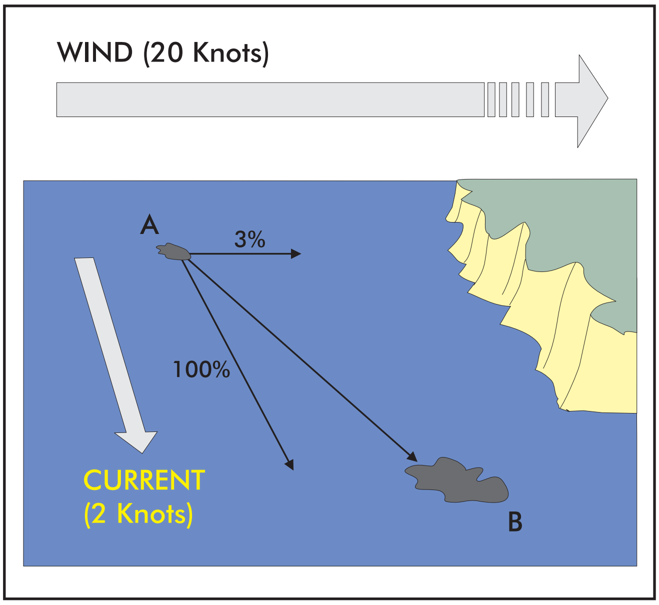


Figure 2: Influence of wind and current on the movement of oil at sea

environmentally sensitive areas where wildlife (e.g. breeding colonies of birds or seals) may be disturbed. A working plan should be prepared using extracts or copies of maps and charts of an appropriate scale which allow annotations to be made. Some basic data may also usefully be included, such as longitude and latitude, the location of the spill source and pertinent coastal features. It may be useful to draw a grid onto the working copy so that any position can be easily identified by grid reference or alternatively by reference to the distance and bearing of a radio beacon.

The task of predicting the position of the oil is simplified if data on winds and currents is available since both contribute to the movement of floating oil. It has been found empirically that floating oil will move downwind at about 3% of the wind speed. In the presence of surface water currents, an additional movement of the oil at 100% of the current strength will be superimposed on any wind-driven motion. Close to land, the strength and direction of any tidal currents must be considered when predicting oil movement, whereas further out to sea the contribution of other ocean currents predominate over the cyclic nature of tidal movement. Thus, with knowledge of the prevailing winds and currents, it is possible to predict the speed and direction of movement of floating oil from a known position, as illustrated in Figure 2 above. Computer models exist which can plot oil spill trajectories. The accuracy of both computer models and simple manual calculations depends on the accuracy of the hydrographic data used and the reliability of forecasts of wind speed and direction.

In view of the errors inherent in oil movement forecasting, it is usually necessary to plan a systematic aerial search to ascertain the presence or absence of oil over a large sea area. A 'ladder search' is frequently the most economical method of surveying an area (Figure 3). When planning a search, due attention must be paid to visibility and altitude, the likely flight duration and fuel availability, together with any other advice the pilot may give. Floating oil has a tendency to become elongated and aligned parallel to the direction of the wind in long and narrow 'windrows' typically 30 - 50 metres apart. It is advisable to arrange a ladder search across the direction of the prevailing wind to increase the chances of oil detection.

Other considerations are haze and light reflection off the sea, which often affects visibility of the oil. Spotting oil is often easiest with the sun behind the observer and it may prove more profitable to fly a search pattern in a different direction to the one originally planned. Sunglasses with polarising lenses can assist the detection of oil at sea under certain light conditions.

Despite making careful predictions and planning a systematic ladder search, the actual pollution observed during the flight may still be different to the situation envisaged. It is important therefore, for contingencies to be borne in mind and adjustments made during the flight, to maximise the chances of finding the oil and plotting its full extent, while still trying to maintain a logical and efficient flight plan.

The search altitude is generally determined by the visibility prevailing. Over open sea areas, in clear weather 1,000-1,500 feet (300-450 metres) frequently proves to be optimal for maximising the scanned area without losing visual clarity. However, it is necessary to drop to half this height or lower in order to confirm any sightings of floating oil or to analyse its appearance. For helicopters, when used closer to shore, and in the absence of any restrictions imposed by the pilot or by the nature of the coastline to be surveyed, a flight speed of 80-90 knots and an altitude of 400 - 500 feet (120-150 metres) often proves a useful starting point. Further adjustment may then be made as appropriate during the course of the flight.

It is essential that observers can keep track of the position of the aircraft, so that progress may be monitored along with any changes that might be necessary in the light of the circumstances noted during the flight. Features and landmarks along the coast may be compared against charts when surveying a shoreline but

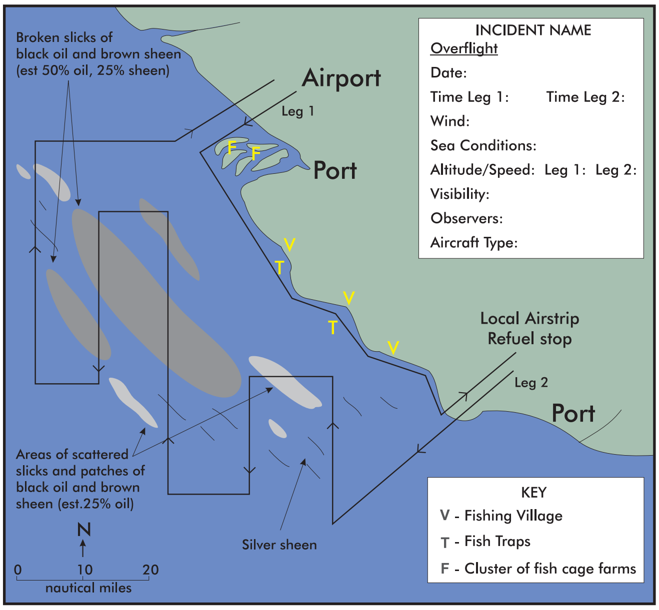


Figure 3: In addition to the oil pollution, a range of other features may also be observed during a reconnaissance flight. These might include response and clean-up activities at sea and on shore, the location of sensitive environmental resources such as wildlife and special habitats, together with commercial interests such as amenity areas, industrial sites and mariculture facilities. These may also be annotated on the final plan, or recorded separately, to assist in the strategic response decision-making process. Drawing the flight path on the map shows which areas have been surveyed. The ladder search pattern shown above was adapted to meet expected oil distribution and light conditions, as there was no wind.

over open water, away from any obvious reference points, it is easy to become disorientated. Ideally an observer will have the opportunity of consulting the aircraft instrumentation in order to ascertain speed, direction and position, but in such an event, it is worth ensuring beforehand that reading these instruments will present no difficulty. Commercial aircraft fitted with GPS equipment (Global Positioning System) enable a pilot to locate accurately the aircraft's position. Portable GPS devices allow ready and accurate recording of waypoints for aircraft location and observed oil.

Throughout the flight, communication with fellow observers and the pilot is important to monitor progress, confirm observations and to discuss and agree any desired and appropriate adjustments to the flight (Figure 4). Headsets are usually available for this and instruction from the pilot on their use should be sought prior to take off to avoid disruption with communications of other aircraft and the traffic control authorities.

Figure 4: The intended flight path and emergency procedures should be discussed with the pilot before takeoff. Observers should work together to confirm sightings and make sure of aircraft instrumentation

Appearance of oil at sea and near to shore

Crude and fuel oils spilled at sea undergo marked changes in appearance over time as a result of weathering processes. It is important for observers to be familiar with these processes so that the presence of spilled oil can be reliably detected and its nature accurately reported.

Most oils spread rapidly over wide areas of the sea surface. Although the oil may initially form a continuous slick this usually breaks up into fragments and windrows due to circulation currents and turbulence (Figures 5 & 6). As the oil spreads and the oil thickness reduces, its appearance changes from the black or dark brown colouration of thick oil patches to iridescent and silver sheen at the edges of the slick (Figure 7). Sheens consist of very thin films of oil (Figure 10), and whilst these areas can be widespread they represent a negligible quantity of oil (Table 2). In contrast, some crude oils and heavy fuel oils are exceptionally viscous and tend not to spread appreciably, but remain in coherent patches surrounded by little or no sheen. A common feature of spills of crude oil and some heavy fuel oils is the rapid formation of water-in-oil emulsions which are often characterised by a brown/orange colouration and a cohesive appearance (Figure 8).

From the air it is notoriously difficult to distinguish between oil and a variety of other unrelated phenomena (Figures 11-15). It is necessary therefore to verify initial sightings of suspected oil by over-flying the area at a sufficiently low altitude to allow positive identification. Aerial observations of shoreline oiling should be confirmed by a closer inspection from a boat or on foot.

Phenomena that most often lead to mistaken reports of oil include: cloud shadows, ripples on the sea surface, differences in the colour of two adjacent water masses, suspended sediments, floating or suspended organic matter, floating seaweed, algal/plankton blooms, seagrass and coral patches in shallow water, and sewage and industrial discharges. A particularly difficult task is to distinguish between operational tank washings from passing vessels and oil originating from an accidental spill. The smaller quantity and coverage of tank washings and their linear distribution are usually indicative.

Recording and reporting

It is important to make notes during the flight of the time and locations of all potentially relevant features observed so as to create a reliable record from which an informative report of the flight can be prepared. Data from GPS devices can be readily downloaded to electronic maps for illustrative purposes. The report should be made promptly after the flight and provide a clear depiction of the nature and extent of oil pollution at sea and close to the shore. By comparison with records from previous flights, an understanding may also be gained on how the situation has developed over time. The nature of the information collected and the way it needs to be recorded and presented will vary depending on the scale of the pollution problem and the level of detail needed to meet the intended purpose of the surveillance flight. The main features of the observed oil that should be recorded are provided in Table 1. Working sketches and annotations will need to be worked up either by hand or computer, to produce a final map for presentation (Figure 3). It is good practice to retain the original sketches and notes in case they may need to be referred to again later.

Photographs provide an invaluable record of oil pollution. Whenever possible, features such as ships and the coastline should be included to give an idea of scale. Relatively fast shutter speeds (1/500th second) are recommended to avoid blurring from the motion and vibration of the aircraft. UV and polarising filters are often useful to cut down glare and can sometimes assist in sharpening the visual definition of oil on the water, although some polarising filters produce colour distortions through aircraft windows made of plastics. Cameras with in-built GPS are useful to maintain a log of photographs taken. Digital images can be rapidly disseminated to a wide audience to assist command and control of the response.

Video cameras can provide an additional tool for recording observations, but filming may prove difficult in turbulence and during aircraft manoeuvering. The use of hand-held cameras is also constrained by the limited field of view through the eyepiece which reduces the ability of the observer to quickly scan the sea surface. An additional observer for video recording is therefore preferable. Down links may allow information to be passed automatically to the ground and allow replays. Hand-held video cameras allow the addition of commentary, which if not added

Figure 5: Very large broken slicks of heavy fuel oil – note the absence of sheen. Viewed from 1,000 feet (~300m)

Figure 6: Windrows of black oil and sheen. Viewed from 900 feet (~250m)

Figure 7: Scattered patches of heavy fuel oil spreading to brown and silver sheen in warm ambient conditions (air temp ~30ºC, water temp ~25ºC). Viewed from 1,000 feet (~300m)

Figure 8: Very large area of orange/brown emulsion, partly held in the harbour by a section of floating boom

Figure 9: Black oil held against a coastal marsh by onshore winds

Figure 10: Extensive area of sheen

Figure 11: Cloud shadows resembling floating oil © Richard Smith

Figure 12: Free floating seaweed and underwater growths of seagrass can also be mistaken for oil – note the organic debris that has washed ashore, further enhancing the false impression of the presence of oil

Figure 13: Sediment plumes disturbed by currents in a shallow area, resembling patches of emulsified light crude oil

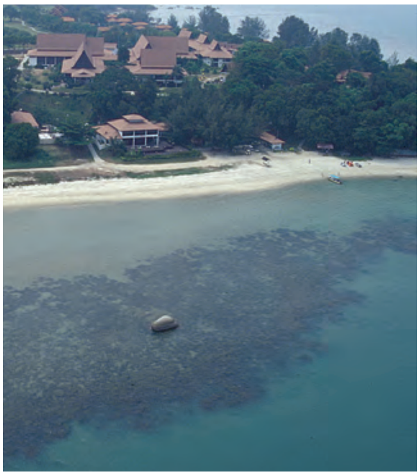
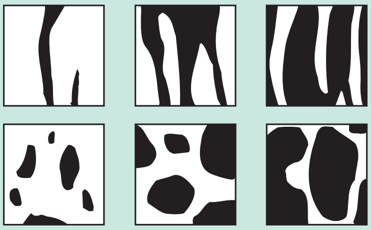


Figure 14: Clumps of coral in shallow water, resembling patches of oil

Figure 15: Nearshore waters affected by discharge of palm oil from a coastal plantation

Feature	Data	Comment
Location and extent	Latitude and longitude (preferably by GPS) for location of slicks GPS readings for centre or edges of large slicks Visual estimates for dimensions of smaller slicks and patches	It is important to retain a sense of scale so that what is observed on the water is not exaggerated when being recorded. It is worth establishing a mental picture of distance on the outward leg of a flight by observing and noting recognisable land features. When observing large areas affected by oil, the presence of any ships is useful in gauging the scale of slicks. Regular reference to GPS readings is useful to confirm estimates made visually.
Colour	For oil slicks: Black, Brown, Orange For sheen: Silver, Iridescent (rainbow), Brown	Colour offers an important indication of oil thickness. For oil slicks, a brown or orange colour indicates likely presence of water-in-oil emulsion. In terms of oil spill response, sheen may be disregarded as it represents a negligible quantity of oil, cannot be recovered or otherwise dealt with to any significant degree by existing response techniques, and is likely to dissipate readily and naturally. Depending on the circumstances, sheen may often be omitted therefore from the final report prepared after the flight.
Character	Windrow, Slick, Patch, Streak	Observers should avoid too many descriptive phrases and should apply their selected terms consistently throughout.
Features	Leading Edge	If the thick oil characterising the leading edge of a slick can be identified, it should be denoted by a heavier line on the plan and referenced.
Coverage	 25% 50% 75%	For response efforts to be focused on the most significant areas of oil pollution, it is important to have information on the relative and heaviest concentrations. To avoid distorted views it is necessary to look vertically down on the oil when assessing the distribution. It is difficult to make an accurate assessment of the % coverage and it is advisable not to try to be too precise with the estimation. The diagrams may be used as a reference guide. More experienced observers may be able to interpolate intermediate coverages.

The adoption of common terms can also provide an indication of the amount of oil present in a given area. In combination, the estimate of % coverage together with selected terms, provides a consistent and flexible method of describing the amount of oil in an area to a degree of accuracy sufficient for response decisions to be made.

Traces	Scattered	Patchy	Broken	Continuous
<10%	25%	50%	75%	>90%

Table 1: Main features that should be recorded during a surveillance flight

in sufficient detail with suitable location references, may make later co-ordination of the video with other observations difficult - especially if extended footage has been produced. Video tape is best used to supplement rather than replace briefings made by experienced observers.

Quantifying floating oil

It is hard to assess accurately the quantity of oil observed at sea, due to difficulties of gauging thickness and coverage. However, by considering certain factors it may be possible to assess the correct order of magnitude of the spill, which may help with planning the required scale of clean-up response. Because of the uncertainties involved, all such estimates should be viewed with considerable caution.

Oils with a low viscosity spread very rapidly and so oil layers quickly reach an average thickness of about 0.1mm. However, the thickness of the oil layer can vary considerably within a slick or patch of oil from less than 0.001mm to more than 1mm. For more viscous oils the oil thickness may remain well in excess of 0.1mm. The appearance of the oil can give some indication of its thickness (Table 2). Some oils form an emulsion by the inclusion of tiny droplets of water, which increases their volume. A reliable estimate of the water content is not possible without laboratory analysis, but figures of 50-75% are typical. The thickness of emulsion can vary considerably depending on the oil type, the sea conditions and whether the emulsion is free-floating or held against a barrier such as a boom or the shoreline. A figure of 1mm may be used as a guide, but thicknesses of 1cm and more can sometimes be encountered and it should be emphasised that the thickness of emulsion and also other viscous oils is particularly difficult to gauge because of their limited spreading. When the sea surface is rough, it can also be difficult or impossible to see less buoyant oil types as they can be swamped by waves, and remain just sub-surface. In cold water some oils with high pour points will solidify into unpredictable shapes and the appearance of the floating portions may disguise the total volume of oil present. The presence of ice flows and snow in such conditions may obscure large amounts or all the oil and will confuse the picture yet further.

In order to estimate the amount of floating oil it is necessary not only to gauge thickness, but also to determine the surface area of the various types of oil pollution observed (Table 1). Due account needs to be taken of the patchy incidence of floating oil so that an estimate may be made of the actual area of coverage relative to the total sea area affected. The extent of the affected sea areas needs to be determined during the flight. If GPS equipment is available, this will enable the limits of the main areas to be recorded relatively easily and accurately. If GPS equipment is not available, the extent of oil must be established by a timed overflight at constant speed.

The following example provides an illustration of the process of estimating oil quantities.

During aerial reconnaissance flown at a constant speed of 150 knots, crude oil emulsion and silver sheen were observed floating within a sea area, the length and width of which required respectively 65 seconds and 35 seconds to overfly. The percentage cover of emulsion patches was estimated at 10% and the percentage cover of sheen at 90%. From this information it can be calculated that the length of the contaminated area of sea is:

$$\frac{\text{65 (seconds) x 150 (knots)}}{\text{3,600 (seconds in one hour)}} = \text{2.7 nautical miles}$$

Similarly, the width of the sea area measured is:

$$\frac{35 \times 150}{3{,}600} = \text{1.5 nautical miles}$$

This gives a total area of approximately 4 square nautical miles, or 14 square kilometres.

For the example given: the volume of emulsion can be calculated as 10% (coverage) of 14 (km^2) x 1,000 (approximate volume in m^3 per km^2 – Table 2). Since 50-75% of this emulsion would be water, the volume of oil present would amount to approximately 400-700 m^3. A similar calculation for the volume of sheen yields 90% of 14 x 0.1, which is equivalent to approximately 1.3 m^3 of oil.

This example also serves to demonstrate that although sheen may cover a relatively large area of sea surface, it makes a negligible contribution to the volume of oil present. It is crucial therefore, that during the overflight the observer is able to distinguish between sheen and thicker patches of oil.

Remote sensing

Cameras relying on visible light are widely used to record the distribution of oil on the sea but can be supplemented by airborne remote sensing equipment which detects radiation outside the visible spectrum and provides additional information about the oil. Remote sensing equipment mounted in aircraft is being used increasingly to monitor, detect and identify sources of marine discharges, including the monitoring of accidental oil spills. These sensors work by detecting different properties of the sea surface which are modified by the presence of oil. The most commonly employed combinations of sensors includes Side-Looking Airborne Radar (SLAR), downward-looking thermal infra-red (IR) and ultra-violet (UV) imaging systems. Other systems such as Forward Looking Infra-Red (FLIR), Microwave Radiometers (MWR), Laser Fluorosensors (LF) and Compact Airborne Spectrographic Imagers (CASI) have the potential to provide additional information. All sensors require highly trained personnel to operate them and interpret the results. The majority of remote sensing systems are bulky and can only be used from dedicated aircraft into which they are installed. However, handheld IR cameras are available which can provide a portable remote sensing system that is not limited to dedicated aircraft.

UV, thermal IR, FLIR, MWR, and CASI are passive sensors, measuring emitted or reflected radiation. With the possible exception of MWR, they are unable to penetrate cloud cover, fog, haze or rain. Their use is consequently limited to clear weather periods. SLAR and LF incorporate an active source of radiation and rely on sophisticated electronic analysis of the return signal to detect oil and in the case of LF, provide some indication of the type of oil. MWR can provide information on the thickness of oil on the sea surface but are unable to do so if the oil has emulsified. MWR and LF imaging systems are research tools and more often sensors relying on this technology can only provide information on oil along a narrow track immediately beneath the aircraft. MWR, LF and IR sensors can all be used at night in clear skies, while radar systems can also penetrate cloud and fog, day or night, and are therefore able to operate under most conditions although they are less effective in both calm conditions and in strong winds. A combination of different devices is usually adopted to overcome the limitations of individual sensors and to provide better information about the extent and nature of the oil. Combined SLAR and IR/UV systems have been used fairly widely during oil spills. SLAR can be flown at sufficient altitude to provide a rapid sweep over a wide area, up to 20 nautical miles either side of the aircraft. However, SLAR is unable to distinguish between very thin layers of sheen and

Oil Type	Appearance	Approximate Thickness	Approximate Volume (m^3/km^2)
Oil Sheen	Silver	>0.0001 mm	0.1
Oil Sheen	Iridescent (rainbow)	>0.0003 mm	0.3
Crude and Fuel Oil	Brown to Black	>0.1 mm	100
Water-in-oil Emulsions	Brown/Orange	>1 mm	1,000

▲ *Table 2: A guide to the relation between the appearance, thickness and volume of floating oil*

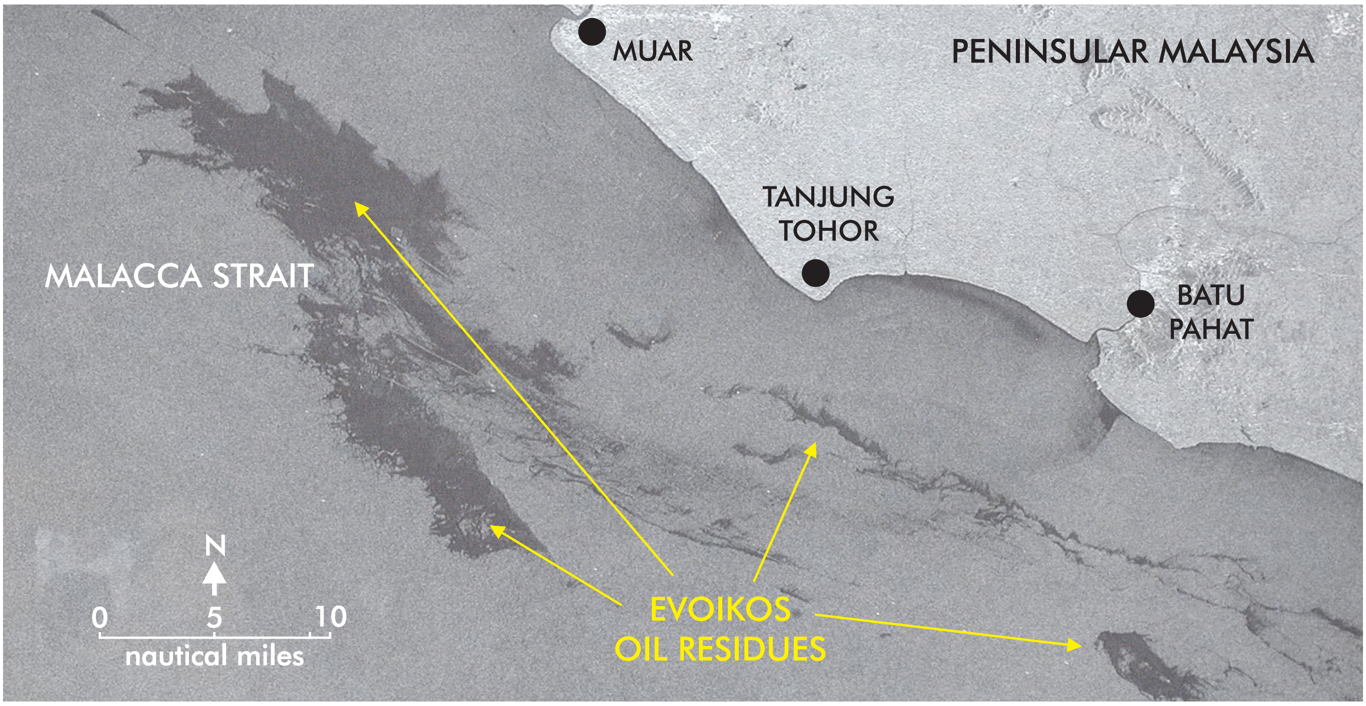


Figure 16: A Sythetic Aperture Radar satellite image of the southern Malacca Strait taken after the EVOIKOS spill in Singapore, showing the oil residues whilst they were moving north-west with the current. Image kindly provided by RADARSAT International © Canadian Space Agency 1997. Received and processed by CRISP, National University of Singapore and distributed under licence by RADARSAT International

thicker oil patches, and the images thus need to be interpreted with caution. Aircraft equipped with a combination of SLAR and IR can define the total extent of the slick using SLAR and then once the oil has been located, provide qualitative information on slick thickness and the areas of heavier pollution with images from the IR sensors. In daylight an IR/UV sensor combination can fulfil a similar function. The UV sensor detects all the oil covered area, irrespective of thickness, whilst the thermal IR sensor is capable, under appropriate conditions, of delineating the relatively thick layers. Signals from all types of sensor are usually displayed and recorded on equipment onboard the aircraft. For the resulting images to be used effectively in the management of the response operations, they would need to be relayed to the command centre, correctly interpreted and then presented in a concise and understandable format. In order that the results from remote sensing systems are correctly interpreted it is usually advisable to confirm the findings with visual observations.

Satellite-based remote sensors can also detect oil on water and because such images cover extensive sea areas, they can provide a comprehensive picture of the overall extent of pollution (Figure 16). The sensors used include those operating in the visible and infra red regions of the spectrum and radar; synthetic aperture radar (SAR). Optical observation of spilt oil requires daylight clear skies, thereby severely limiting the application of such systems. SAR is not limited by the presence of cloud and since it does not rely on reflected light also remains operational at night. However, radar imagery often includes a number of anomalous features which can be mistaken for oil, such as wind shadows and rain squalls and so requires expert interpretation. A further limitation of all satellite imagery is that the frequency with which a satellite passes over the same areas ranges from a few days to weeks depending on the particular orbit. This delay can be partially overcome by interrogation of more than one satellite platform and, where possible, by positioning the satellite's transmitter beam at different angles on a given path. In addition the systems on board usually have to be instructed to acquire the imagery from the area of interest. The imagery then has to be transmitted from a ground receiving station for interpretation. However, this processing time has decreased sufficiently for some systems such that satellite imagery may provide an effective operational tool in the management of spill response.

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include on-site clean-up advice, pollution damage assessment, assistance in spill response planning, and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution through its library, wide range of technical publications, videos and website. For further information contact:

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